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MILITARY SPECIFICATIONS

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INTRODUCTION

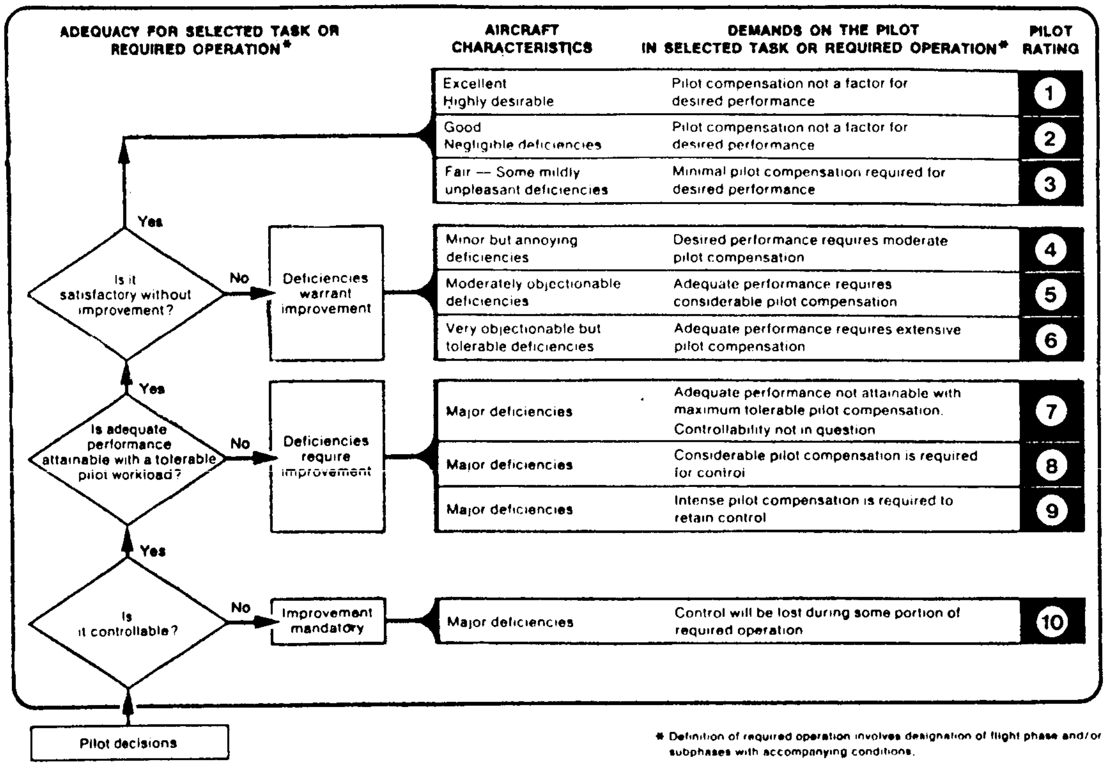
The current situation relative to the military specification is that there is not one specific model of turbulence which people are using. Particular disagreement exists on how turbulence levels will vary with qualitative. It does not tie you down to specifics. When it comes to flying quality specifications, many people feel that we should stay with the definitions of the Cooper-Harper rating scale, as shown in Figure 1, but allow the levels to shift depending on the level of turbulence.

RAE Bedford and British Airways have recorded thousands of landings, examined them, studied them, and tried to discover instances of encountering wind shear, and how many landings get close to the edge. Apparently, the British flight recording information is better than ours. It contains more information, such as the pilot's action; i.e., where the throttle is, where the wheel is, etc. If wind shear is encountered and the pilot goes to full thrust without the flight recorder being aware of this, the derived wind shear, or the reconstruction of the accident after the fact, may not be correct. Accident investigations at this time seem to look at where the throttle ended up and use this to reconstruct last few seconds of flight. In my opinion, this is not a good enough way to obtain a description of the encountered wind shear. You may come out with an entirely wrong answer.

There is a ride quality specification in the MIL-SPEC (reference 1) having to do with flight control systems design that is related to a turbulence model. The structures people also have specifications which relate to turbulence and the problems that they encounter. There is no lack of specifications in the military; it is simply that perple are using different models.

Reference 2 specifies isotropic turbulence models which are either the von Karman or Dryden as noted in Figure 2. Turbulence longitudinal scales twice the lateral scales are recommended. Equations that define the spectra are also provided in this document.

MIL-F8785C (reference 1) is the current version of the flying quality specification. It has a turbulence model, and it has the turbulence intensities, σ's, varying with altitude in the way shown in Figures 3 and 4. The scales vary with altitude. Mil-standard, which is a new proposed version of the MIL-8785, has the characterization also shown in Figure 3. We, at Calspan, have a third. You can see right away that in all models the scale L_W is proportional to altitude, so it goes to zero and zero altitude. The only difference in L_W between models is that Calspan uses a factor of two, so its scale is half the other model's value. When you plot the model parameters, you see that there is disagreement on how they vary. The mil-standard draft for σ_W is in the middle of Figure 4 and Calspan's suggestion is on the bottom. We are also working more now with helicopters and a helicopter specification is being developed. Figure 5 shows the probability that sigma exceeds a certain value given that you have encountered turbulence.



LEVEL 1 PR ≤ 3.5

LEVEL 2 $3.5 < PR \leq 6.5$

LEVEL 3 $6.5 < PR \leq 9$

Figure 1. Cooper-Harper Handling Qualities Rating Scale. (from reference 3).

ORIGINAL PAGE IS
OF POOR QUALITY

VON KARMAN

DRYDEN

AFFDL-TR-72-41 (reference 2)

ISOTROPIC TURBULENCE

LONGITUDINAL SCALES EQUAL TWICE LATERAL SCALES

$$L_u = 2\,L_v = 2\,L_w$$

DEFINITIONS REFLECTED IN SPECTRA EQUATIONS

Figure 2. Continuous Turbulence Models.

Figure 6 shows data from a B-66 program which is a plot of the frequency of encounter based on the RMS value. The RMS values are typically computed from a 60-second record. Real turbulence is not stationary. The specification deals entirely with clear-air turbulence. It is not associated with thunderstorms or the large-scale phenomena being discussed here. This is a whole new area to address. If you look at a 60-second record of wind shear with conventional statistics, the RMS will be disproportunately large.

Figure 7 shows differences between the models. We have different definitions for light, moderate and severe. For instance, the British classify an RMS of 10 as heavy turbulence; Calspan classifies this value as the most severe that you would encounter, as far as the flying quality specification is concerened. The definition of light turbulence differs as well.

Figure 8 is an example of wind shear concepts prior to JAWS, different types of boundary layer profiles. None of these examples resembles the kind of wind shear being discussed here.

Figure 9 illustrates the other part of the design problem, which is a discrete wind disturbance. In a helicopter, for instance, if you are landing behind a treeline, you experience a decrease in wind and then get a jet effect near the ground below the level of the tree branches. I have landed at little airports in light airplanes where you get a very pronounced wind effect from trees which is very predictable. The wind disappears, and you just have to be ready for it.

For those of you who are not well-versed in the MIL-SPEC rating scale for flying qualities, Figure 1 shows a 10-point scale. Proper use of this involves a pilot asking himself questions and answering his own questions. This helps the pilot orient his thinking towards rating the handling qualities of the airplane for a specific task. The first question is whether the airplane is controllable. If it is not, the pilot is forced to give it a rating of 10. Another question is whether adequate performance is attainable with a tolerable pilot workload. All these questions are subjective. The pilot has to make a judgment about what is tolerable.

Table I gives the mil-standard suggested specifications. In extreme turbulence, it allows you to say that you still have a level-one airplane even though the flying qualities are such that control can be maintained only long enough to fly out of the disturbance. That's a pretty poor situation. In severe turbulence, a pilot rating of 7-1/2 can be called level one. At Calspan, we don't agree with that. We would like to see those definitions of levels stay the same and have a different level permitted when you get into heavy turbulence. For example, if you take a level-one airplane and fly into an extreme situation, you might have a level-three pilot workload at that point; that's okay as long as it's flyable and you can get out of it. That's the alternate way which we are proposing to view the effect of turbulence. For level one, the definition in turbulence would be that flying qualities are clearly adequate for the mission flight phase, as shown in Table II. You can accomplish the mission here in the military sense versus not accomplishing the mission, giving up, and coming home. You require this capability for light turbulence. In moderate turbulence, we are saying the capability is not required, and likewise for severe. At level two, you have flying qualities adequate to accomplish the mission flight phase, but some increase in workload or degradation of the mission in effectiveness both exist. In moderate

MIL-F-8785C (reference 1)

$$\sigma_w = 0.1\, U_{20}$$

$$\sigma_u = \sigma_v = \frac{\sigma_w}{(0.177 + .000823h)^{0.4}} \qquad \text{BELOW 1000 FT}$$

$$L_u = L_v = \frac{h}{(0.177 + .000823h)^{1.2}} \qquad 10 < h < 1000 \text{ FT}$$

$$L_w = h$$

MIL-STD (reference 4)

$$\sigma_u = 5 \text{ FT/SEC} \sim \text{MODERATE}$$

$$\sigma_w = .117\, h^{1/3}\, \sigma_u \qquad 10 < h < 1750 \text{ FT}$$

$$\frac{\sigma_u^{\,2}}{L_u} = \frac{\sigma_v^{\,2}}{2L_v} \qquad \text{THUS} \quad \sigma_v = \sqrt{2}\, \sigma_u$$

$$L_u = L_v = 145\, h^{1/3} \qquad 10 < h < 1750 \text{ FT}$$

$$L_w = h$$

CALSPAN (reference 2)

$$\sigma_u = 6 \text{ FT/SEC} \quad \text{OPERATIONAL}$$

$$\sigma_w = .083\, h^{1/3}\, \sigma_u \qquad h < 1750 \text{ FT}$$

$$\sigma_v = \sigma_u$$

$$L_u = 2L_v = 145\, h^{1/3} \qquad h < 1750 \text{ FT}$$

$$2L_w = h$$

Figure 3. Dryden Model Scales and RMS Intensities.

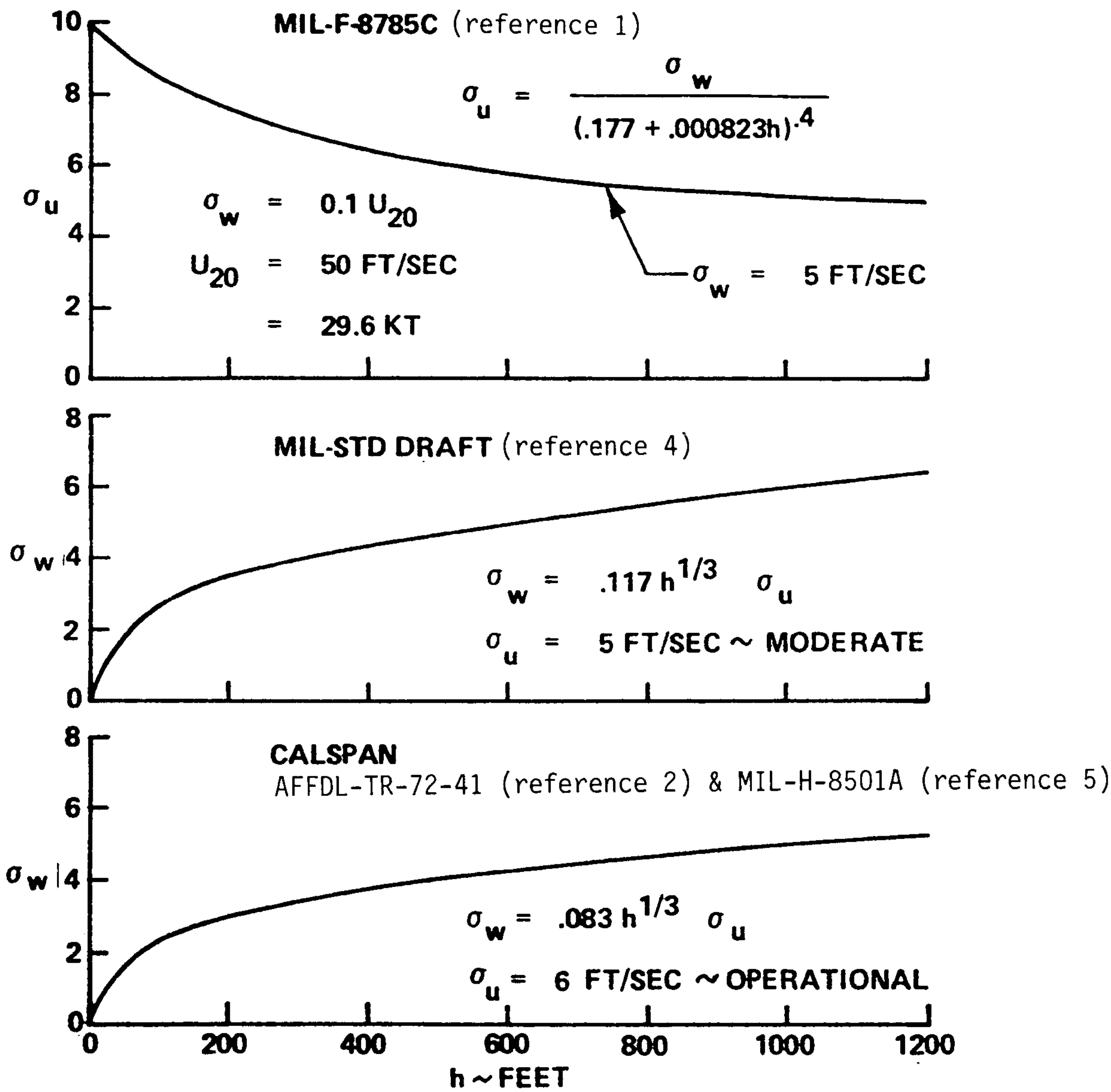


Figure 4. Dryden Model Scales and RMS Intensities.

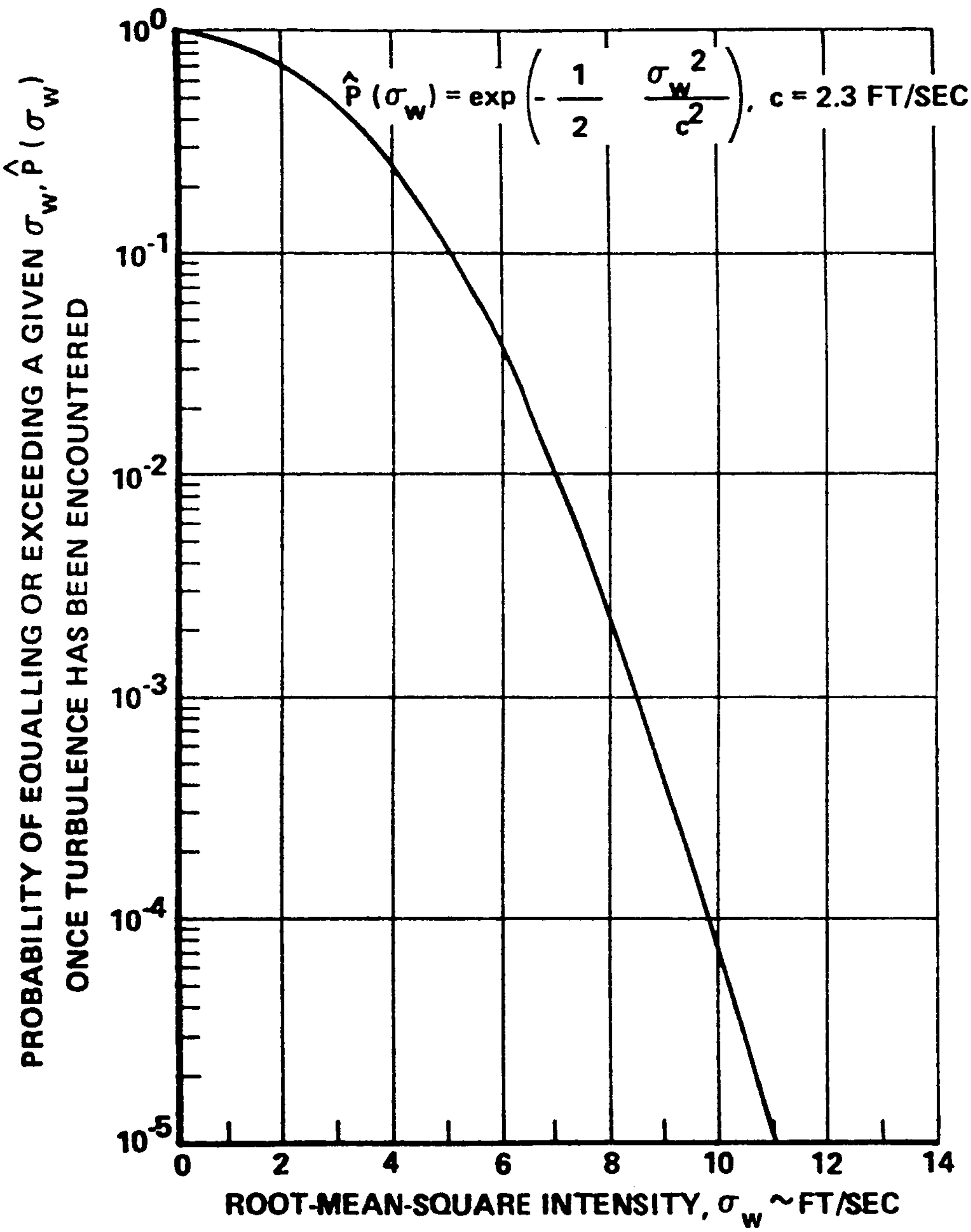


Figure 5. Probability of exceeding a given σ given that turbulence is encountered.

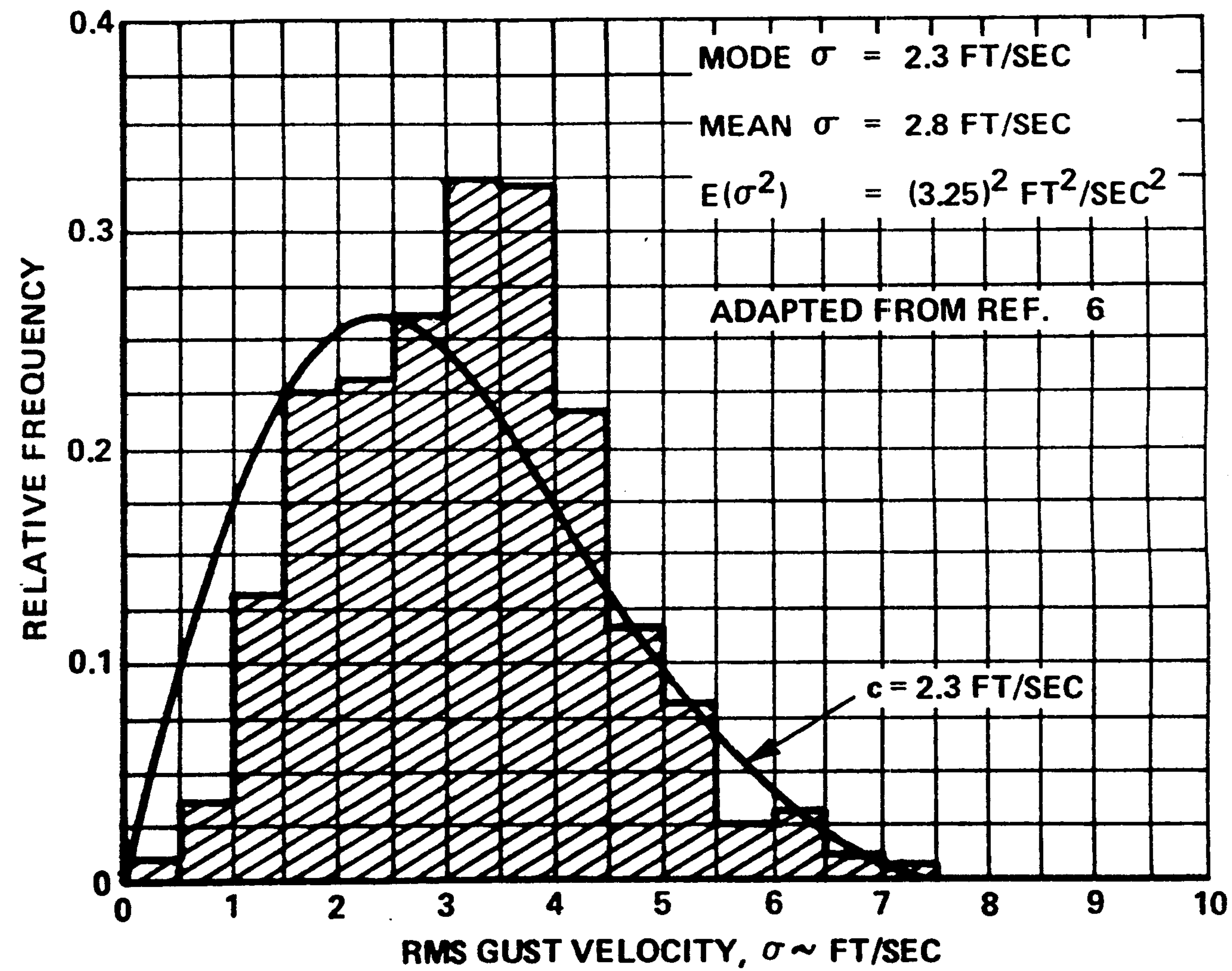


Figure 6. Relative Frequency Distributions of RMS Gust Velocity from B-66 Low-Level Program.

MIL-F-8785B	LOW ALTITUDE (reference 7)
CLEAR AIR	σ_w = 6.7 FT/SEC
THUNDERSTORM	= 21 FT/SEC

MIL-F-8785C	LOW ALTITUDE	MEDIUM/HIGH ALTITUDE (reference 1)
$\sigma_w = .1\ U_{20}$	σ_w	σ_w h = 10 KFT
LIGHT (WIND)	2.53 FT/SEC	5 FT/SEC
MODERATE	5.07	10
SEVERE	7.61	21

BRITISH AvP970 (reference 8)	
LIGHT	σ_w = 3 FT/SEC
MODERATE	5
HEAVY	10
EXTREME	20

MIL-STD DRAFT (reference 4)	
LIGHT	σ_u = 3 FT/SEC
MODERATE	5
SEVERE	10
EXTREME	24

CALSPAN	h < 1750 FT	h > 1750 FT
ENVIRONMENTS	σ_u	σ_u
OPERATIONAL	6 FT/SEC	6 FT/SEC
MOST SEVERE	10	20

Figure 7. RMS Turbulence Characterizations.

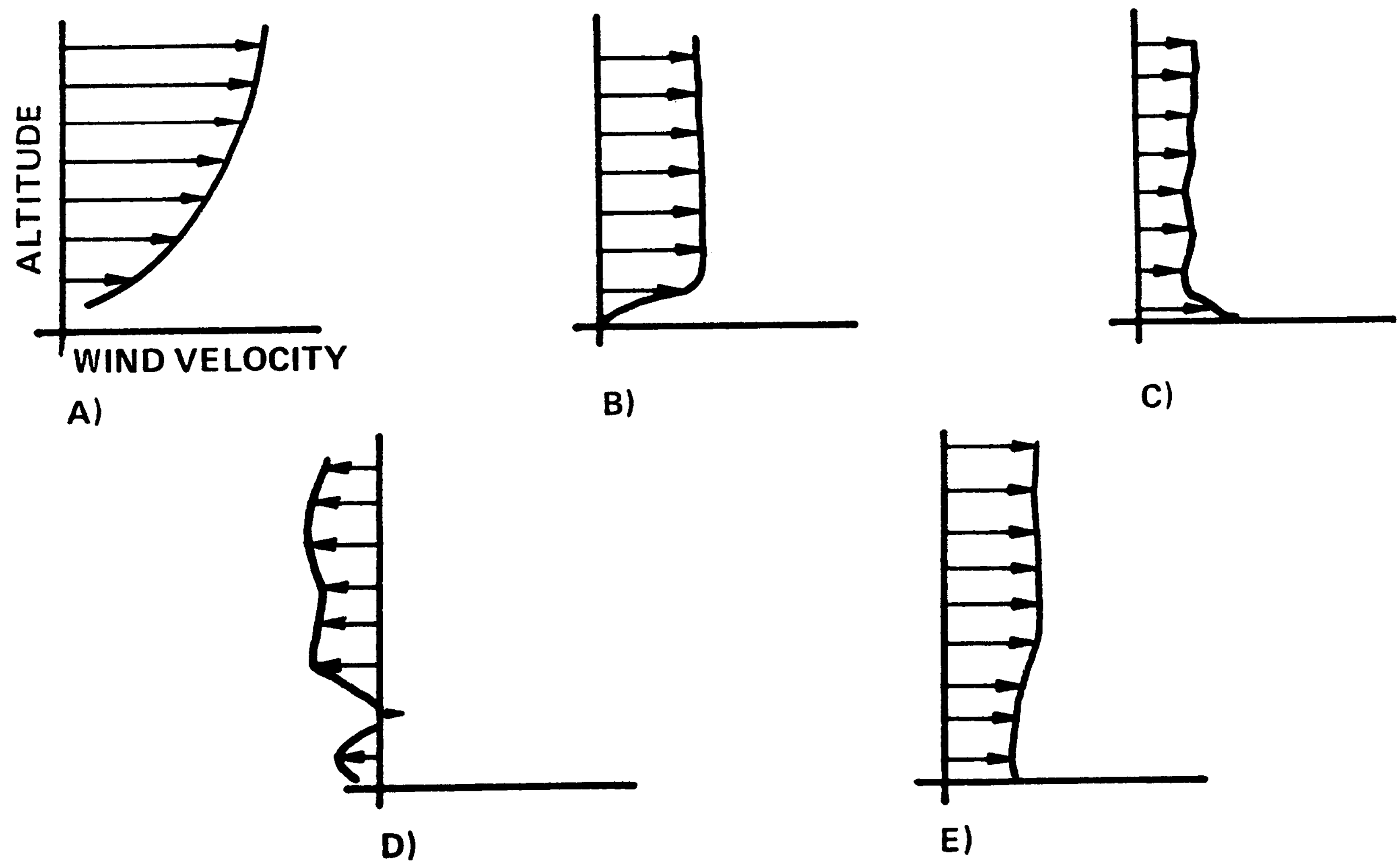
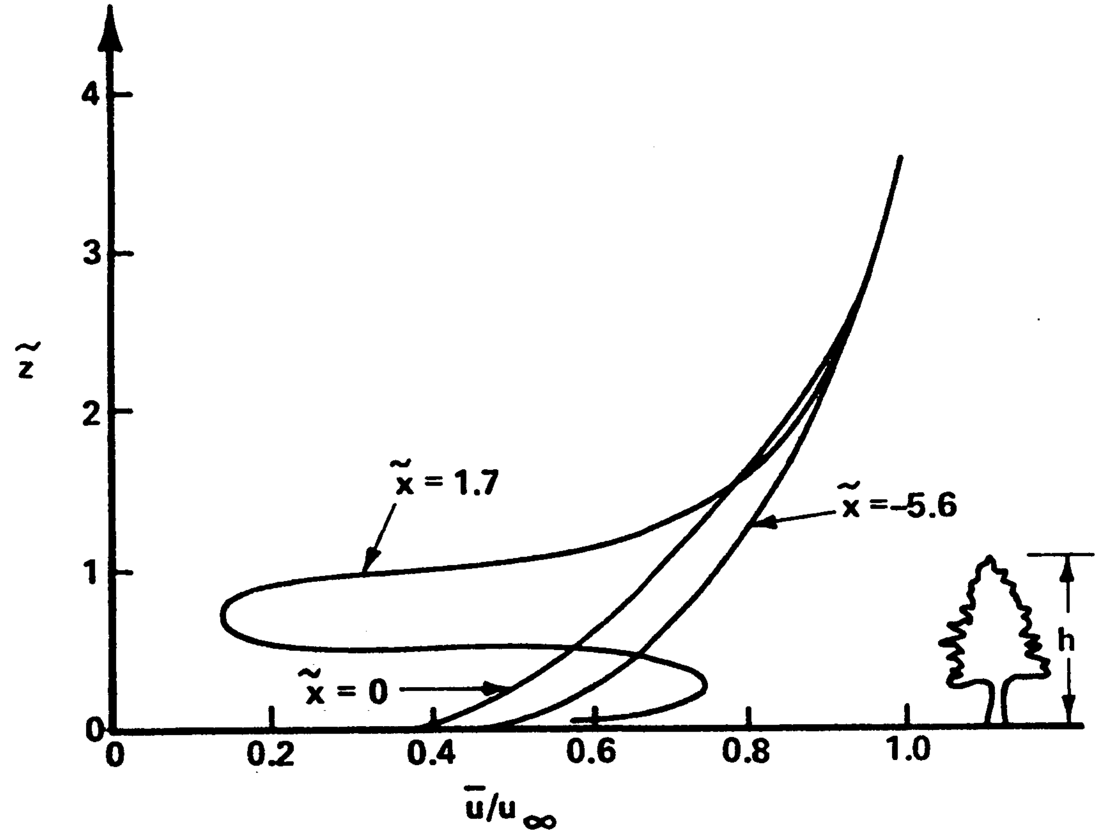


Figure 8. Representative Wind Shears.



h = HEIGHT OF TREES

x = HORIZONTAL DISTANCE DOWNWIND OF EDGE OF FOREST

$\tilde{x}$ = x/h

z = HEIGHT ABOVE FLOOR OF FOREST

$\tilde{z}$ = z/h

$\bar{u}$ = LOCAL MEAN VELOCITY

u_∞ = REFERENCE VELOCITY AT REFERENCE HEIGHT WELL ABOVE FOREST CANOPY

Figure 9. Normalized Velocity Profiles Near the Edge of a Forest--Showing the Jetting Action in the Region of the Trunks--Tree Spacing ≃ h.

turbulence, you require the capability. In severe turbulence, the capability is not required. This leads to a different design requirement on the flight control system in heavy turbulence. You can have a requirement for a level-three airplane or a level-two airplane in very heavy turbulence. This may end up designing the flight control system, whereas requiring level one in light, or no, turbulence may not be the critical design point.

QUESTION:

With regard to the change in velocity that you just talked about, one way of interpreting that is that it requires the level-three airplane in a sense to be as good as the level-one in severe turbulence. Is that realistic?

RESPONSE:

If an airplane is level one in clear air, no turbulence, what we are suggesting is that you would allow it to degrade to level two or three in moderate to heavy turbulence, and still satisfy the spec. However, you would not call it a level one airplane in that situation.

QUESTION:

If the airplane was in what otherwise was considered to be a level three situation, you still have a required capability to satisfy it with severe turbulence...if it's level three for other reasons. Now, in addition, if you have severe turbulence, this is more restrictive in some sense.

RESPONSE:

Yes, it could end up designing the airplane. In fact, there are some instances where they should have looked at heavy turbulence in the design because the airplane is almost unflyable in turbulence. If you look at smooth air and look in the simulator without exercising this area, you will design a dangerous airplane.

Table I. Definition of Levels When Levels Are Defined by Cooper-Harper Rating Scale.

LEVEL	ATMOSPHERIC DISTURBANCES			
	LIGHT	MODERATE	SEVERE	EXTREME
1	3-1/2	5-1/2	7-1/2	Flying qualities such that control can be maintained long enough to fly out of the disturbance.
2	6-1/2	7-1/2	Flying qualities such that control can be maintained long enough to fly out of the disturbance.	Flying qualities such that pilot can regain control after being upset.
3	9-1/2	Flying qualities such that control can be maintained long enough to fly out of the disturbance.	Flying qualities such that pilot can regain control after being upset.	No requirement

Table II. Minimum Operational Capability Required.

LEVEL	LEVEL DEFINITION	ATMOSPHERIC DISTURBANCES		
		LIGHT	MODERATE	SEVERE
1	Flying Qualities Clearly Adequate for the Mission Flight Phase.	Required Capability	Capability Not Required	Capability Not Required
2	Flying Qualities Adequate to Accomplish the Mission Phase, but Some Increase in Pilot Workload or Degradation in Mission Effectiveness, or Both, Exists.	Required Capability	Required Capability	Capability Not Required
3	Flying Qualities Such That the Aircraft Can Be Controlled Safely in the Mission Flight Phase, but Pilot Workload is Excessive or Mission Effectiveness is Inadequate, or Both.	Required Capability	Required Capability	Required Capability

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